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WINDOWS - MEASUREMENTS OF AIR FLOW CAPACITY

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ABSTRACT

In natural ventilation systems fresh air is often provided through opening of windows. However, the knowledge of the performance of windows is rather limited. Computation of natural ventilation air flow through windows is most commonly made using discharge coefficients, that are regarded as being constant.

The reported results show that the discharge coefficient for a window opening cannot be regarded as a constant and that it varies considerably with the size of the opening area, the window type and the temperature difference. Therefore, the use of a constant value can lead to serious errors in the prediction of air flow capacity.

KEYWORDS

Natural ventilation, window, discharge coefficient, laboratory measurements.

INTRODUCTION

In natural ventilation systems fresh air is often provided through opening of windows. There is a wide range of possibilities with regard to selection of window type, size and location. However, the knowledge of the performance of individual windows is rather limited and is based on theoretical assumptions of the main driving forces, effective areas and air flow within rooms. Therefore, it is only possible in the window design for natural ventilation to give rough estimates of the air flow rate and thermal comfort that can be expected. Some window types are regarded as better than others, but this is mainly based on qualitative measures and the differences and limitations in the application of individual window types cannot be quantified.

Computation of natural ventilation air flow through windows is most commonly made using discharge coefficients, that quantify the air flow efficiency of an opening or alternatively the air flow resistance of openings. Many of the discharge coefficient values used are derived from data traditionally used for fluid flow in pipes. Entry conditions such as incidence of openings to the approaching wind, presence of insect screens, adjacent wing walls, overhangs or inclined window sashes can significantly influence the discharge due to momentum effects at windward openings. Also downstream of an opening surfaces parallel to the flow and close to the edge of the opening can influence the jet issuing from an opening but are rarely accounted for although they can have significant influence on discharge. A discharge coefficient value of 0.6 for a sharp-edged rectangular opening is often used for window or door openings. The value is regarded as constant and independent of the above influences as well as window opening angle (opening area) and pressure and temperature differences across the opening.

Much more work needs to be done regarding these influences to provide reliable design data for computation of natural ventilation through window openings that can improve the window design methods to a level where they can match the design methods of air inlets in mechanical ventilation. This paper describes the results of a series of laboratory measurements that is performed to estimate the discharge coefficient for two different window types as a function of opening angle and pressure and temperature difference. Information about air flow from window openings in the room and estimation of thermal comfort parameters can be found in Heiselberg (1999), Nielsen (2000) and Svidt (2000).

AIR FLOW THROUGH WINDOWS

The air flow through a window depends on the chosen natural ventilation strategy, see Figure 1. Single-sided ventilation relies on openings being on only one side of the ventilated enclosure. With a single opening in the room the main driving force for natural ventilation in winter is the thermal stack effect where the air will flow into the room in the bottom half of the window and out of the room in top half of the window. The stack induced flow increases with the vertical separation of the openings. The main driving force in summer will be the wind turbulence. In cross and stack ventilation there are ventilation openings on both sides of a space. The air flows from one side of the building to the other and leaves through another window or door. Cross ventilation is usually wind driven while stack ventilation is thermal (and wind) driven. With such ventilation strategies there will only be an inflow of air through the window (or outflow) and the pressure difference will be much higher. The capacity of the opening will not depend on the distribution of the opening area but only on the total area.

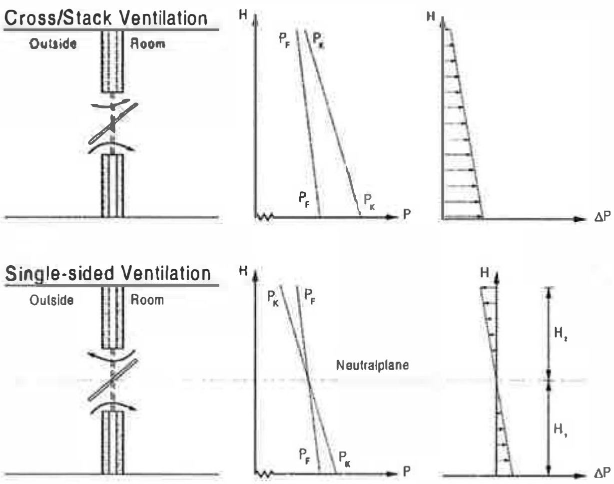


Figure 1. Air flow through a window with single-sided and cross ventilation strategy.

This paper focuses on the situation with cross ventilation and unidirectional flow through the window. The air flow through a window opening can be determined by:

$$Q = A_c v_c \tag{1}$$

where A_c is the minimum cross section area of the flow through the opening and v_c is the air velocity of the flow through this area.

The two quantities can be related to known ones by:

$$A_c = C_c A \tag{2}$$

$$v_c = C_v v_{theo} \tag{3}$$

where C_c is a contraction coefficient, A the opening area, C_v is a velocity coefficient depending on friction in the opening and v_{theo} is the theoretically obtainable velocity when no friction is taken into consideration. v_{theo} can be determined by:

$$v_{theo} = \sqrt{\frac{2\Delta p}{\rho}} \tag{4}$$

where Δp is the pressure difference across the opening and ρ is the density of air.

Equation (1) can be rewritten as:

$$Q = C_d A \sqrt{\frac{2\Delta P}{\rho}} \tag{5}$$

where C_d is the discharge coefficient defined as the product of the contraction (C_c) and the velocity (C_v) coefficient.

The discharge coefficient is a characteristic parameter for a specific window and takes both the contraction and the friction loss in the window opening into account. The size of the coefficient is only known for very simple opening types. For windows, which have a complicated geometrical structure, the size of the coefficient is unknown and its dependence on parameters as for example opening area, velocity level (pressure difference) and temperature difference is not known either. Andersen (1996) contains a more thorough discussion of inlet and outlet coefficients.

LABORATORY SET-UP

The investigations are performed in a laboratory test room with the size of Length × Width × Height = 8 m × 6 m × 3 m, see Figure 2. The room is divided into two separate rooms by an insulated wall. The small room can be cooled down to a temperature of about 0°C, while the large room can be kept at normal room temperature. Two different window types have been placed in the insulated wall, see Figure 3a. Window type 1 is a combined side/bottom hung window that is placed close to the occupied zone. Window type 2 is a narrow bottom hung window that is placed high in the room.

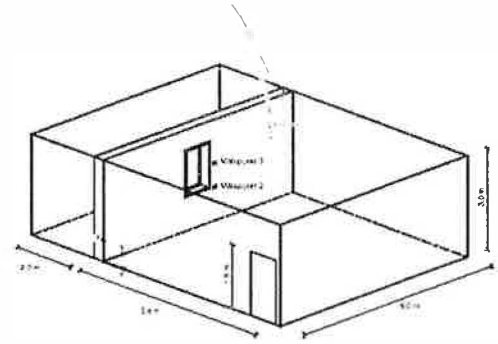
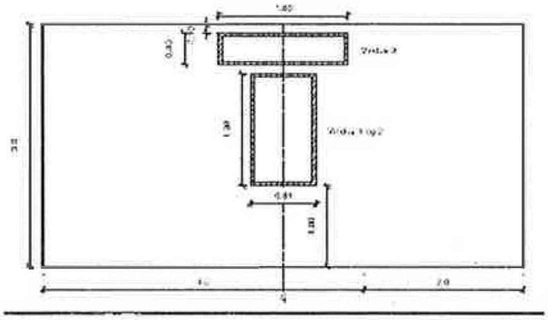


Figure 2. Sketch of laboratory test room.

A



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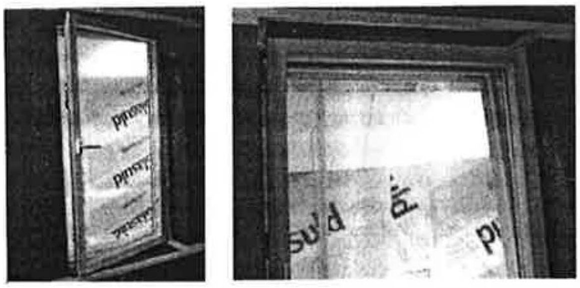

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Figure 3. A) Sketch of window location in insulated wall. B) Photo of window type 1, C) Photo of window type 2.

MEASUREMENT RESULTS

The discharge coefficient is calculated from Eqn. (5), which is based on measurements of the geometrical opening area, volume flow rate and pressure difference across the opening. The estimation of the geometrical opening area of the window is very difficult because of the complicated geometry of the frames and especially at small opening angles the uncertainty is high. Air is supplied to the cold room and extracted from the warm room. The volume flow rate is measured in the supply air channel as well as the pressure in each room. The volume flow rate through the window is found as the measured supply air flow rate but corrected according to the measured exfiltration of the cold room. The exfiltration was about 2-15% of the volume flow rate through the window with the highest values for small opening areas. The absolute value of the discharge coefficient is therefore uncertain especially at small opening angles and measured values above 1 can be caused by incorrect estimation of the opening area and exfiltration.

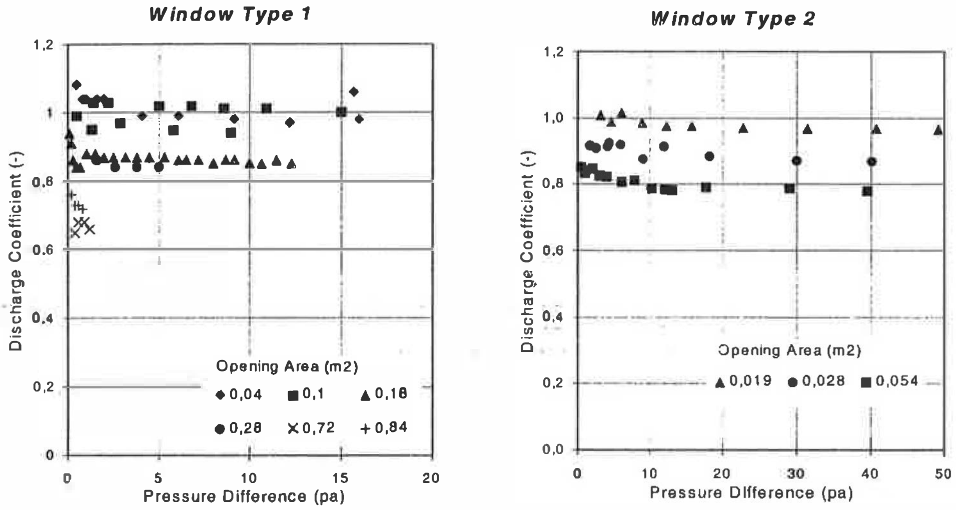

Figure 4. Discharge coefficient, C_d, for window types 1 and 2 as a function of pressure difference for different opening areas.

Figure 4 shows the discharge coefficient as a function of the pressure difference across the opening for different opening areas for both window types. It can be seen that the discharge coefficient is not a constant but dependent on both window type and opening area. It can also be seen, especially in the case of window type 1, that the value of the discharge coefficient varies at small pressure differences across the opening while it becomes constant at large pressure differences. This indicates a Reynolds number dependency that might be important to take into consideration as natural ventilation systems often operate at very small pressure differences.

Figure 5 shows the discharge coefficient for window type 1 as a function of a reduced Archimedes number ($\Delta T/Q^2$). It can be seen that in a situation with both a temperature and a pressure difference across the opening the discharge coefficient can be described as a function of the Archimedes number and the opening area, and that the value is considerably reduced at large temperature differences.

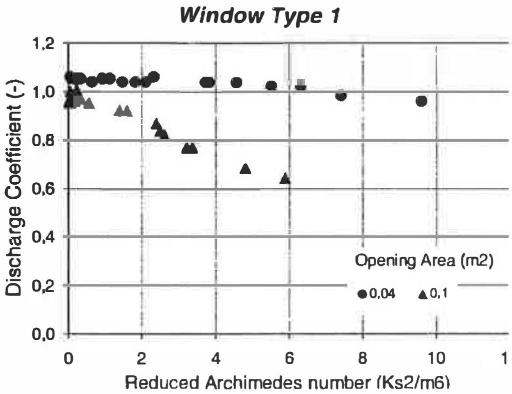

Figure 5. Discharge coefficient, C_d, for window type 1 (side hung) as a function of a reduced Archimedes number ($\Delta T/Q^2$).

CONCLUSIONS

The results show that the discharge coefficient for a window opening cannot be regarded as a constant as it varies considerably with the size of the opening area, window type and temperature difference. The use of a constant value can lead to serious errors in the prediction of air flow capacity.

The results have been promising. The work will continue to improve the measurement method and to collect more data to be able to develop methods that include the variation of the discharge coefficient in natural ventilation design.

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